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PHYTOEXTRACTION OF NICKEL BY SELECTED SPECIES OF LAWN GRASSES FROM SUBSTRATES CONTAMINATED WITH HEAVY METALS

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Abstract. In the recent years many attentions dedicates contamination environment heavy metals. For main source of this pollution was considered the industrial activity of man, burning mineral fuels, motorization, metallurgy, and different technological processes. On the pollution of heavy metals be subject particularly strongly the terrains industrialized and large municipal centres. Methods were sought cheap cleaning environment from heavy metals. The phytoremediation can be one of such methods using, the plants to phytoextraction these metals. Phytoextraction of nickel by *Poa pratensis* L., cv. 'Evora', *Festuca arundinacea* Schleb., cv. 'Asterix' and *Festuca rubra* L. *sensu lato* cv. 'Jasper' was investigated in the conducted experiment. Selected species of lawn grasses are used in lawn-seed mixtures. Plants were grown in substrates artificially contaminated with heavy metals. The aim of the conducted studies was to determine which of the applied lawn grass species when growing in a substrate contaminated with heavy metals will accumulate the highest amounts of nickel and whether increasing doses of heavy metals introduced to the substrate will have an effect on the growth and fresh matter of the aboveground parts in the analysed species of lawn grasses. Increasing doses of heavy metals, irrespective of harvest date, did not have a significant effect on fresh matter of the aboveground parts of analysed grasses. Among the investigated grass species, growing in substrates contaminated with heavy metals, *Poa pratensis* L. 'Evora' and *Festuca arundinacea* Schleb. 'Asterix' turned out to be species exhibiting the highest capacity to accumulate nickel. The smallest mean content of nickel was found in *Festuca rubra* L. *sensu lato* 'Jasper'. Analysed lawn grasses species, particularly *Poa pratensis* L. 'Evora' and *Festuca arundinacea* Schleb. 'Asterix', may be used in the management of soils contaminated with nickel.

Key words: phytoremediation, nickel concentration index, *Poa pratensis* L., *Festuca arundinacea* Schleb.

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INTRODUCTION

Efficient and cost-effective methods of decontamination are searched for in the protection of soils in industrial and urban areas. We may distinguish many technologies causing deactivation or removal of toxins from the substrate; however, most of them are very expensive methods. An alternative for these physico-chemical methods is offered by the process of phytoremediation, consisting in the application of plants in the reduction of contents of harmful substances or in the stabilization of the substrate and the inhibition of erosion processes [Salt et al. 1998, US EPA Technology Innovative Office 1998, Phytoremediation Work Team US EPA 1999]. According to Schnoor [2002], phytoremediation is a technology, which uses higher plants in the stabilization and removal or reduction of the amounts of contaminants in soils, bottom deposits or surface and underground waters. In the opinion of Gawroński [2009], in the practice of remediation of industrial areas the section of phytoremediation called phytoextraction proves to be most successful. Thus plants able to survive and live on soils contaminated with heavy metals are searched for [Bosiacki 2008, Bosiacki and Wolf 2008a, Bosiacki 2009]. In urban and industrial green areas lawn grasses are highly frequently found forms of vegetation. They are popular thanks to the broad range of their climatic and soil requirements, low cultivation costs, as well as diverse applications.

According to Rutkowska and Pawluśkiewicz [1996], lawns play a primary role in urban and transport green areas, with their total proportion estimated at 50%, and in some cities as much as 90% of the total. Established on soils contaminated with heavy metals, they may remediate them, absorbing certain amounts of these metals to their aboveground parts [Bosiacki and Wolf 2008 b, c].

In view of the attractiveness of the method using grasses to decontaminate areas polluted with heavy metals it was decided to conduct investigations described in this study. The analyses were performed using three grass species, commonly used in lawn-seed mixtures, which were sown on a substrate artificially contaminated with nickel, cadmium and lead. The aim of the conducted investigations was to determine which of the applied species of lawn grasses, sown on a substrate contaminated with heavy metals would accumulate the highest amounts of nickel and whether increasing doses of heavy metals introduced to the substrate would have an effect on the growth and green matter of aboveground parts of the analysed species of lawn grasses.

MATERIAL AND METHODS

The pot experiment was conducted during the two years of the study in the spring-summer season, under controlled conditions, in an unheated greenhouse at the Department of Horticultural Plant Nutrition, the Poznań University of Life Sciences.

In the vegetation experiment three species of lawn grasses were used, with one selected cultivar representing each of the following:

– Kentucky bluegrass *Poa pratensis* L., cv. 'Evora',
– reed fescue *Festuca arundinacea* Schleb., cv. 'Asterix',
– red fescue *Festuca rubra* L. *sensu lato*, cv. 'Jasper'.

The selection of the above mentioned species was connected with their specific features, determining their suitability for application in green areas as the primary components of lawn-seed mixtures.

These grasses were grown in a substrate artificially contaminated with nickel, cadmium and lead, in order to determine their suitability for applications in urban green areas contaminated with these metals, as well as methods to remove nickel compounds from soil. The vegetation experiment was performed in drainless containers of 6 dm^3 in the completely random design. It consisted of twelve combinations, of which each comprised eight replications. Individual doses of the above mentioned metals result in different contamination levels, i.e.:

– 0 mg $Ni \cdot dm^{-3}$, 0 mg $Cd \cdot dm^{-3}$, 0 mg $Pb \cdot dm^{-3}$ – the control object,
– 50 mg $Ni \cdot dm^{-3}$, 1 mg $Cd \cdot dm^{-3}$, 100 mg $Pb \cdot dm^{-3}$ – elevated contents,
– 75 mg $Ni \cdot dm^{-3}$, 5 mg $Cd \cdot dm^{-3}$, 500 mg $Pb \cdot dm^{-3}$ – weak contamination,
– 150 mg $Ni \cdot dm^{-3}$, 10 mg $Cd \cdot dm^{-3}$, 1000 mg $Pb \cdot dm^{-3}$ – medium contamination.

For Poland such criteria were established by employees of the Institute of Soil Science and Plant Cultivation. Six degrees of soil contamination were distinguished, with the corresponding different recommendations concerning their use, while soils were divided into three classes depending on their composition and reaction [Kabata-Pendias et al. 1993].

Table 1. Contents of nutrients ($mg \cdot dm^{-3}$), pH (H_2O) and EC ($mS \cdot cm^{-1}$) in highmoor peat, mineral soil and in the mixture of mineral soil with highmoor peat
Tabela 1. Zawartość składników pokarmowych ($mg \cdot dm^{-3}$), pH (H_2O) oraz EC ($mS \cdot cm^{-1}$) w torfie wysokim, glebie mineralnej oraz mieszance gleby mineralnej z torfem wysokim

Nutrients Składniki	Highmoor peat Torf wysoki	Mineral soil Gleba mineralna	Mineral soil + highmoor peat Gleba mineralna + torf wysoki
$N - NH_4$	28.00	treaces – ślady	12.00
$N - NO_3$	7.00	5.00	4.00
P	37.00	31.00	34.00
K	11.00	75.00	82.00
Ca	107.00	210.00	245.00
Mg	21.00	22.00	42.00
$S - SO_4$	10.00	5.00	7.00
Na	11.00	15.00	10.00
Cl	27.00	17.00	18.00
Fe	50.20	48.00	51.40
Zn	1.30	4.20	5.10
Cu	0.40	4.50	3.90
Mn	1.30	11.4	18.50
B	0.43	0.68	0.40
Mo	treaces – ślady	0.10	0.08
pH	3.86	5.03	4.67
EC	0.16	0.25	0.19

The substrate, in which all grass species were grown, was a mixture of highmoor peat and mineral soil (slightly loamy sand) at a volumetric ratio of 1:1. The volume of 1 dm^3 substrate weighed 945 grams, while the weight of the substrate per each container was 5670 g. Contents of nutrients ($mg \cdot dm^{-3}$), pH (H_2O) and EC ($mS \cdot cm^{-1}$) in the substrate before the establishment of the experiment were determined using the universal method [according to Nowosielski 1974, after IUNG 1983], (tab. 1). In order to obtain pH within the range of 6.5–7.0 the substrate was limed. The dose of $CaCO_3$ at 6 g per 1 dm^3 was established on the basis of the neutralization curve. Contents of nutrients were introduced to the substrate in the form of a multicompound slow-release fertilizer Hortiform Mg at 4 g per 1 dm^3 (tab. 2).

At seven days after liming of the substrate heavy metals were added, i.e. nickel, cadmium and lead in individual doses, with all the three metals added jointly to each container. The following compounds of these elements were applied: for nickel – nickel sulfate $NiSO_4{\cdot}7H_2O$, for cadmium – cadmium sulfate $3CdSO_4{\cdot}8H_2O$, and for lead – lead acetate $(CH_3COO)_2Pb{\cdot}3H_2O$ in form of solution.

Table 2. The composition of a multicompound fertilizer Hortiform Mg
Tabela 2. Skład nawozu wieloskładnikowego Hortiform Mg

Element – Składnik	%
Total – Całkowity N	8.0
$N\text{-}NH_4$	2.0
N from urea form N z ureaformu	6.0
Soluble only in hot water: Rozp. tylko w gorącej wodzie	3.6
Soluble in cold water Rozp. w zimnej wodzie	2.4
P_2O_5	11.0 (8% soluble in neutral solution of ammonium citrate and water rozp. w obojętnym roztworze cytrynianu amonu i wodzie 7% soluble in water – rozp. w wodzie)
Total – Całkowity K_2O soluble in water – rozp. w wodzie	5.0 4.5
Total – Całkowity MgO soluble in water – rozp. w wodzie	13.0 3.5
SO_3 soluble in water – rozp. w wodzie	8.0
B	0.01
Co	0.002
Cu	0.01
Fe	0.5
Mn	0.1
Mo	0.001
Zn	0.01

Seeds of the three grass species were sown at the end of April. Seeds were hand-sown at 2.5 g seeds per each container and next covered with a thin layer of sand and watered to constant weight. Seedlings emerged after around a dozen days.

Plants were watered as needed, depending on ambient temperature (once weekly to constant weight). Before each mowing (once on month from May to August) the height of grasses was measured, while after mowing harvested grass was weighed in order to determine green matter. Due to the longer germination period of red fescue seeds as well as the slower growth of that species, the first (May) harvest was not performed.

The experiment was completed with the collection of substrate samples (with two samples each) from each container, in which the analysed plant was growing, in order to determine soluble forms of nickel. Moreover, samples of plant material were also collected (aboveground parts of plants from each container) for the determination of their nickel, cadmium and lead contents.

Nutrients were determined in $mg \cdot dm^{-3}$ using the universal method [according to Nowosielski 1974, after IUNG 1983] in CH_3COOH solution at a concentration of 0.03 $mol \cdot dm^{-3}$: $N – NH_4$ and $N – NO_3$ by distillation [Starck 1969], P – by colorimetry using the vanadium molybdenum method, K, Ca and Na – by flame photometry, Mg – by atomic absorption (ASA), Cl and $S – SO_4$ – by nephelometry. The other components (Fe, Mn, Cu, Zn) and nickel were determined in $mg \cdot dm^{-3}$ in the extract according to Lindsay by the flame ASA technique. The extract according to Lindsay contains in 10 dm^3: 50 g EDTA (ethylenediaminetetraacetic acid), 90 ml 25% NH_4OH solution, 40 g citric acid and 20 g $Ca(CH_3COO)_2 \cdot 2H_2O$. The reaction of the substrate expressed in pH was determined by potentiometry in H_2O (the substrate: water ratio of 1:2), while EC by conductometry in $mS \cdot cm^{-1}$.

The collected plant material, comprising the aboveground parts (from all harvests), was predried in an extraction drier at a temperature of 55°C for 48 h. Such dried material was ground in a mixer. Next it was transferred at 2.5 g to porcelain crucibles and mineralized in a LINN combustion furnace by Elektro Therm at a temperature of 450°C. Residue after mineralization was dissolved in 10% HCl and transferred to flasks of 50 cm^3. Nickel content in plant material was determined by atomic absorption in an AAS – 3 spectrophotometer by Zeiss.

Statistical analyses in the conducted investigations were performed in the STAT program and comprised bifaktor analyses of variance for data on plant height, fresh matter of aboveground parts of plants and one factor analyses of variance for nickel content in the substrates after the completion of the experiment, contents of nickel in dry matter of aboveground parts in the analysed species of lawn grasses. Differences between means were determined using the Duncan test at the significance level $\alpha = 0.05$.

RESULTS

***Plant height and fresh matter of aboveground parts in Poa pratensis* L. 'Evora'.** When investigating the effect of increasing doses of heavy metals, irrespective of the harvest date, it was confirmed statistically that the highest dose of heavy metals introduced to the substrate had the biggest inhibitory effect on the mean height of *Poa pratensis* L. 'Evora' (tab. 3). The biggest height of plants was recorded in the first two (May and June) cuts. The other two harvests were characterised by significantly smaller heights of plants.

Increasing doses of metals, irrespective of the harvest date, did not have a significant effect on mean height in *Festuca arundinacea* Schleb. 'Asterix' (tab. 4). Only in the first (May) harvest date a significant effect of the highest dose of heavy metals on a reduction of plant height was found. Irrespective of the doses of metals the biggest mean height in reed fescue from individual cuts was observed for that harvested in May. Plants harvested in July and August were characterised by the smallest mean height.

Table 3. The effect of harvest date and doses of Ni, Cd and Pb on height (cm) of aboveground parts in *Poa pratensis* L. 'Evora'
Tabela 3. Wpływ terminu zbioru i dawek Ni, Cd, Pb na wysokość (cm) części nadziemnych *Poa pratensis* L. 'Evora'

Doses of Dawki Ni/Cd/Pb ($mg \cdot dm^{-3}$)	Harvest date – Termin zbioru				
	May Maj	June Czerwiec	July Lipiec	August Sierpień	mean średnia
0	17.15 de	18.43 e	13.53 abcd	10.95 ab	15.01 b
50/1/100	18.63 e	18.43 e	12.58 abcd	9.83 a	14.86 b
75/5/500	15.03 bcde	16.38 cde	12.73 abcd	11.78 abc	13.98 ab
150/10/1000	12.98 abcd	14.18 abcde	10.65 ab	10.90 ab	12.18 a
Mean – Średnia	15.94 b	16.85 b	12.37 a	10.86 a	

Means followed by the same letters are not significantly different for P < 0.05
Średnie oznaczone tymi samymi literami nie różnią się istotnie dla p < 0,05

Table 4. The effect of harvest date and doses of Ni, Cd and Pb on height (cm) of aboveground parts in *Festuca arundinacea* Schleb. 'Asterix'
Tabela 4. Wpływ terminu zbioru i dawek Ni, Cd, Pb na wysokość (cm) części nadziemnych *Festuca arundinacea* Schleb. 'Asterix'

Doses of Dawki Ni/Cd/Pb ($mg \cdot dm^{-3}$)	Harvest date – Termin zbioru				
	May Maj	June Czerwiec	July Lipiec	August Sierpień	mean średnia
0	19.05 e	13.90 cd	10.40 ab	7.73 a	12.77 a
50/1/100	19.48 e	10.83 abc	9.48 a	7.72 a	11.87 a
75/5/500	18.98 e	14.11 cd	9.88 a	8.03 a	12.75 a
150/10/1000	14.83 d	13.58 bcd	10.28 ab	10.30 ab	12.24 a
Mean – Średnia	18.08 c	13.10 b	10.01 a	8.44 a	

Means followed by the same letters are not significantly different for P < 0.05
Średnie oznaczone tymi samymi literami nie różnią się istotnie dla p < 0,05

In the June cut of *Festuca rubra* L. *sensu lato* 'Jasper' the smallest height of plants was found for the substrate not contaminated with metals (tab. 5). Plants growing on the substrate with an elevated content of heavy metals as well as the substrate weakly contaminated with metals were significantly taller than plants from the control object. In the other harvests no significant differences were found in the height of plants under the influence of increasing doses of metals.

Irrespective of metal doses, the smallest mean fresh matter was found in *Poa pratensis* L. 'Evora' for the last (August) cut (tab. 6). In the other harvest dates no significant differences were found in the fresh matter of plants. Irrespective of harvest date, increasing doses of metals did not have a significant effect on the weight of plants. For all the harvest dates, for all the doses of metals the biggest fresh matter of plants was recorded in June for the substrate with elevated contents of nickel, cadmium and lead, being 7.01 times bigger in relation to the weight of plants produced on this substrate in August. The largest sum of fresh mass was obtained in substrate from dose of 50Ni/1Cd/100 Pb mg·dm^{-3}.

Table 5. The effect of harvest date and doses of Ni, Cd and Pb on height (cm) of aboveground parts in *Festuca rubra* L. *sensu lato* 'Jasper'
Tabela 5. Wpływ terminu zbioru i dawek Ni, Cd, Pb na wysokość (cm) części nadziemnych *Festuca rubra* L. *sensu lato* 'Jasper'

Doses of Dawki Ni/Cd/Pb (mg·dm^{-3})	Harvest date – Termin zbioru				
	May Maj	June Czerwiec	July Lipiec	August Sierpień	mean średnia
0	-	4.50 a	14.33 b	16.58 b	11.06 a
50/1/100	-	14.40 b	17.46 b	15.75 b	15.85 a
75/5/500	-	15.13 b	15.21 b	13.78 b	14.70 a
150/10/1000	-	9.86 ab	10.46 ab	11.71 ab	10.66 a
Mean – Średnia	-	10.47 a	14.25 a	14.39 a	

Means followed by the same letters are not significantly different for P < 0.05
Średnie oznaczone tymi samymi literami nie różnią się istotnie dla p < 0,05

Table 6. The effect of harvest date and doses of Ni, Cd and Pb on fresh matter (g) of aboveground parts in *Poa pratensis* L. 'Evora'
Tabela 6. Wpływ terminu zbioru i dawek Ni, Cd, Pb na świeżą masę (g) części nadziemnych *Poa pratensis* L. 'Evora'

Doses of Dawki Ni/Cd/Pb (mg·dm^{-3})	Harvest date – Termin zbioru					
	May Maj	June Czerwiec	July Lipiec	August Sierpień	mean średnia	sum suma
0	52.10 abc	74.30 bc	55.46 abc	12.87 a	48.68 a	194.73
50/1/100	49.25 abc	91.45 c	43.05 abc	13.05 a	49.20 a	196.68
75/5/500	41.95 abc	64.10 abc	53.75 abc	17.18 a	44.24 a	176.98
150/10/1000	31.45 ab	42.50 abc	42.95 abc	19.28 ab	34.05 a	136.18
Mean – Średnia	43.69 b	68.09 b	48.80 b	15.59 a		

Means followed by the same letters are not significantly different for P < 0.05
Średnie oznaczone tymi samymi literami nie różnią się istotnie dla p < 0,05

Similar results were recorded in case of *Festuca arundinacea* Schleb. 'Asterix' (tab. 7). Irrespective of metal doses, the smallest mean fresh matter of plants was found in the last (August) cut. The biggest fresh matter was produced in the May and June cut dates. Irrespective of harvest dates, no significant differences were found in terms of mean fresh matter of plants under the influence of increasing doses of nickel, cadmium or lead. For all the harvest dates and for all the doses of metals the biggest fresh matter of plants was found in case of the May cut for the substrate with an elevated content of heavy metals, as it was 9.19 times bigger in relation to that of plants produced on this substrate in August. The largest sum of fresh mass was obtained in substrate from dose of 50Ni/1Cd/100Pb mg·dm^{-3}.

Table 7. The effect of harvest date and doses of Ni, Cd and Pb on fresh matter (g) of above-ground parts in *Festuca arundinacea* Schleb. 'Asterix'
Tabela 7. Wpływ terminu zbioru i dawek Ni, Cd, Pb na świeżą masę (g) części nadziemnych *Festuca arundinacea* Schleb. 'Asterix'

Doses of Dawki Ni/Cd/Pb (mg·dm^{-3})	Harvest date – Termin zbioru					
	May Maj	June Czerwiec	July Lipiec	August Sierpień	mean średnia	sum suma
0	80.73 cde	75.60 cde	36.45 abc	14.65 a	51.86 a	207.43
50/1/100	110.65 e	82.22 cde	37.08 abc	12.04 a	60.50 a	241.99
75/5/500	87.00 de	66.20 bcde	46.95 abcd	12.25 a	53.10 a	212.40
150/10/1000	50.70 abcd	48.73 abcd	45.42 abcd	23.32 ab	42.04 a	168.17
Mean – Średnia	82.27 c	68.19 c	41.47 b	15.57 a		

Means followed by the same letters are not significantly different for P < 0.05
Średnie oznaczone tymi samymi literami nie różnią się istotnie dla p < 0,05

Table 8. The effect of harvest date and doses of Ni, Cd and Pb on fresh matter (g) of above-ground parts in *Festuca rubra* L. *sensu lato* 'Jasper'
Tabela 8. Wpływ terminu zbioru i dawek Ni, Cd, Pb na świeżą masę (g) części nadziemnych *Festuca rubra* L. *sensu lato* 'Jasper'

Doses of Dawki Ni/Cd/Pb (mg·dm^{-3})	Harvest date – Termin zbioru					
	May Maj	June Czerwiec	July Lipiec	August Sierpień	mean średnia	sum suma
0	-	23.00 a	54.00 a	21.35 a	32.78 a	98.35
50/1/100	-	22.30 a	52.83 a	25.90 a	33.68 a	101.03
75/5/500	-	12.74 a	33.40 a	13.54 a	19.89 a	59.68
150/10/1000	-	4.31 a	9.10 a	10.65 a	8.02 a	24.06
Mean – Średnia	-	15.59 a	37.33 a	17.86 a		

Means followed by the same letters are not significantly different for P < 0.05
Średnie oznaczone tymi samymi literami nie różnią się istotnie dla p < 0,05

Increasing doses of nickel, cadmium and lead as well as individual harvest dates did not have a significant effect on fresh matter of *Festuca rubra* L. *sensu lato* 'Jasper' (tab. 8). Despite statistically non-significant differences in the month of June a considerable reduction, by 5.34 times, was found for fresh matter of plants growing in the substrate, to which the biggest dose of the analysed heavy metals was added in relation to that obtained from the substrate not contaminated with metals. The matter of plants growing in the substrate with medium heavy metal contamination in July was by 5.93 times and in August it was 2 times in relation to fresh matter of plants produced on these dates in the substrate not contaminated with heavy metals. The largest sum of fresh mass was obtained in substrate from dose of 50Ni/1Cd/100Pb mg·dm^{-3}.

Nickel content in the substrate after the completion of cultivation of analysed grass species. In all the substrates contaminated with metals after the completion of the experiment smaller amounts of nickel were found in relation to the introduced dose of this metal (fig. 1). The lowest content of nickel in relation to the introduced dose of this metal was found for the substrate, in which *Poa pratensis* L. 'Evora' was growing. The biggest amount of nickel was observed in the substrates, in which *Festuca rubra* L. *sensu lato* 'Jasper' was growing.

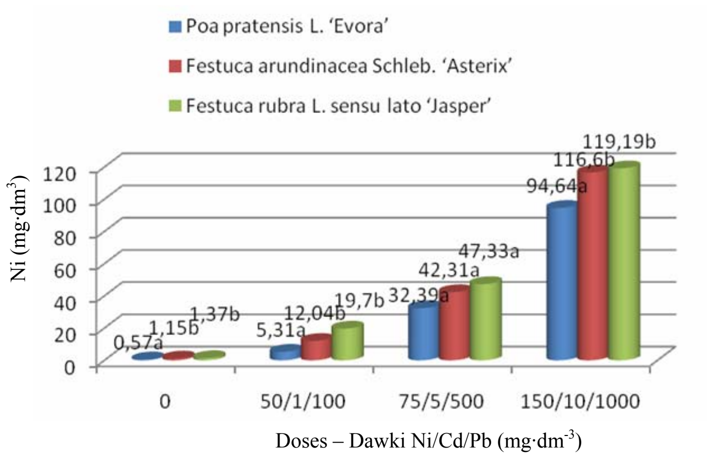

Fig. 1. Nickel content (soluble forms) in the substrate after the completion of the experiment
Ryc. 1. Zawartośc niklu (form rozpuszczalnych) w podłożu po zakończeniu doświadczenia

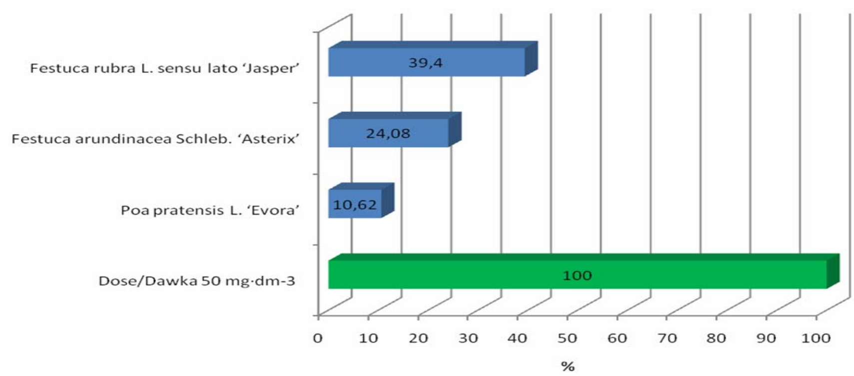

Fig. 2. Residue of nickel (%) in the substrate with an elevated content of heavy metals after the cultivation of analysed species of lawn grasses
Ryc. 2. Pozostałość niklu w procentach w podłożu o podwyższonej zawartości metali ciężkich po uprawie badanych gatunków traw gazonowych

The contents of Ni, introduced to the substrate (100%) and the residue (%) in the substrate following cultivation of the analysed species of lawn grasses present figures 2, 3 and 4. In the substrate, to which 50 mgNi·dm^{-3} were introduced, the smallest amount of nickel was left in the substrate (10.62%) after the cultivation of *Poa pratensis* L. 'Evora'. In the substrate contaminated with 75 mg Ni·dm^{-3} the least of this metal (43.19%) was also found after the cultivation of *Poa pratensis* L. 'Evora'. A similar dependence was found for the substrate contaminated with 150 mg Ni·dm^{-3}, where the smallest level of this metal (63.09%) was recorded also after the cultivation of *Poa pratensis* L. 'Evora'.

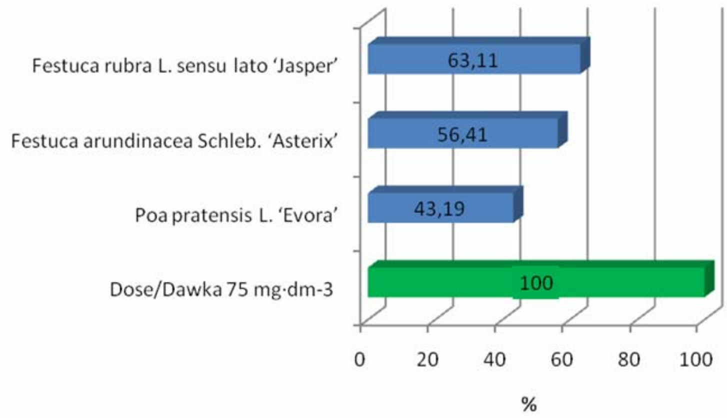

Fig. 3. Residue of nickel (%) in the substrate weakly contaminated with heavy metals after the cultivation of analysed species of lawn grasses
Fig. 3. Pozostałość niklu w procentach w podłożu słabo zanieczyszczonym metalami ciężkimi po uprawie badanych gatunków traw gazonowych

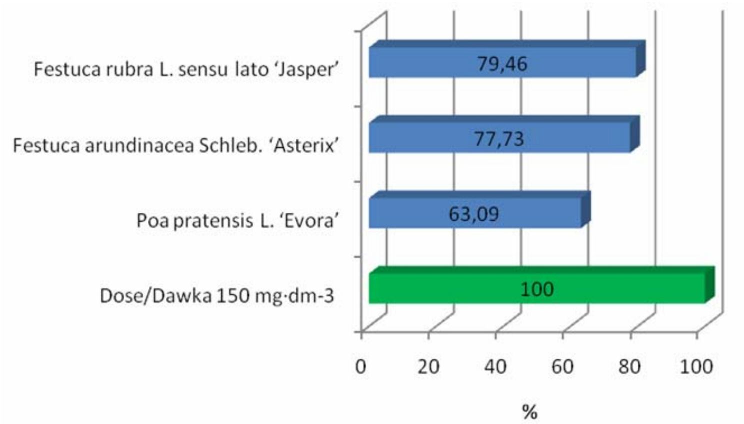

Fig. 4. Residue of nickel (%) in the substrate with a medium content of heavy metals after the cultivation of analysed species of lawn grasses
Fig. 4. Pozostałość niklu w procentach w podłożu średni zanieczyszczonym metalami ciężkimi po uprawie badanych gatunków traw gazonowych

Nickel content in aboveground parts of alanysed grass species. The content of nickel in the aboveground parts of *Poa pratensis* L. 'Evora' increased with an increase in the doses of heavy metals introduced to the substrate (fig. 5). In the substrate to which no nickel was introduced, no significant differences were found in the amounts of this metal in the successive harvest dates. In the substrate with an elevated content of

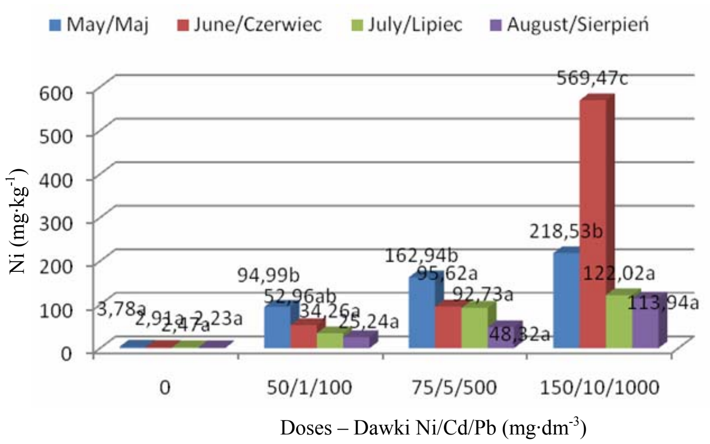

Fig. 5. Nickel content (in d.m.) in aboveground parts of *Poa pratensis* L. 'Evora' depending on the doses of metals and harvest date

Ryc. 5. Zawartość niklu (w s.m.) w części nadziemnej *Poa pratensis* L. 'Evora' w zależności od dawki metali oraz terminu zbioru

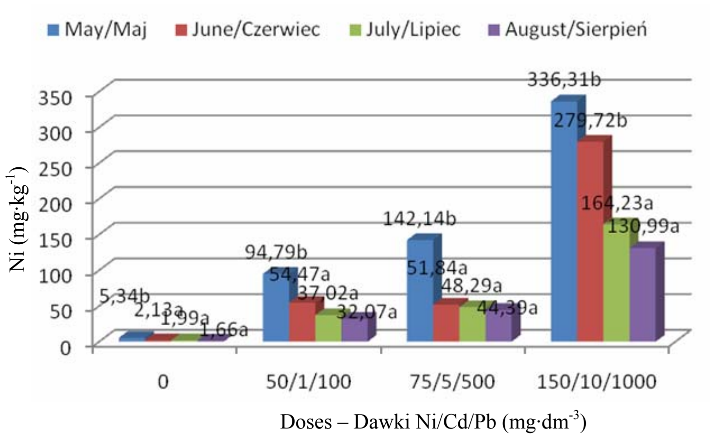

Fig. 6. Nickel content (in d.m.) in the aboveground parts of *Festuca arundinacea* Schleb. 'Asterix' depending on doses of metals and harvest date

Ryc. 6. Zawartość niklu (w s.m.) w części nadziemnej *Festuca arundinacea* Schleb. 'Asterix' w zależności od dawki metali oraz terminu zbioru metals and the weakly contaminated substrate, the highest content of Ni was observed in plants harvested in May. In the substrate, to which the highest doses of heavy metals were introduced, the biggest amounts of nickel were recorded in plants harvested in June.

In *Festuca arundinacea* Schleb. 'Asterix' in the substrate with no nickel added, the substrate with an elevated content of metal and the substrate weakly contaminated with metals the highest Ni content was found in plants harvested in May (fig. 6). Plants harvested in the other months were characterised by a significantly lower amount of nickel in the aboveground parts. In the substrate with medium heavy metal contamination the highest content of Ni was found in plants harvested in May and June.

In *Festuca rubra* L. *sensu lato* 'Jasper' statistically significant differences in the content of nickel were found only in plants growing in the substrate with medium contamination with Ni, Cd and Pb (fig. 7). The highest content of nickel was observed for red fescue harvested in June. In the other substrates no significant differences were recorded in the content of nickel in the aboveground parts of red fescue, harvested on different dates.

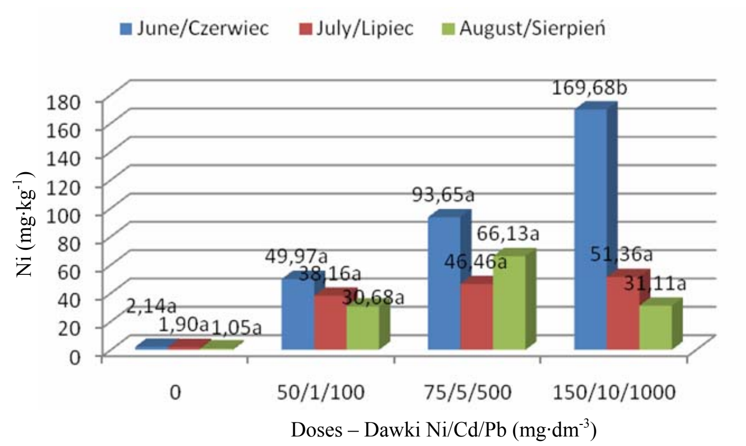

Fig. 7. Nickel content (in d.m.) in the aboveground parts of *Festuca rubra* L. *sensu lato* 'Jasper' depending on doses of metals and harvest date

Ryc. 7. Zawartość niklu (w s.m.) w części nadziemnej *Festuca rubra* L. *sensu lato* 'Jasper' w zależności od dawki metali oraz terminu zbioru

Nickel concentration index. In *Poa pratensis* L. 'Evora' in all the cuts the highest nickel concentration index was observed in plants growing in the substrate, to which the highest doses of nickel, cadmium and lead were introduced (fig. 8). The smallest nickel concentration index was found in the substrate with an elevated content of Ni, Cd and Pb. In plants growing in the substrate with an elevated metal content and the substrate weakly contaminated with heavy metals, May proved to be the month, in which the highest nickel concentration index in plants was observed. In turn, in the substrate with a medium contamination with nickel, cadmium and lead the highest nickel concentration index was found in June.

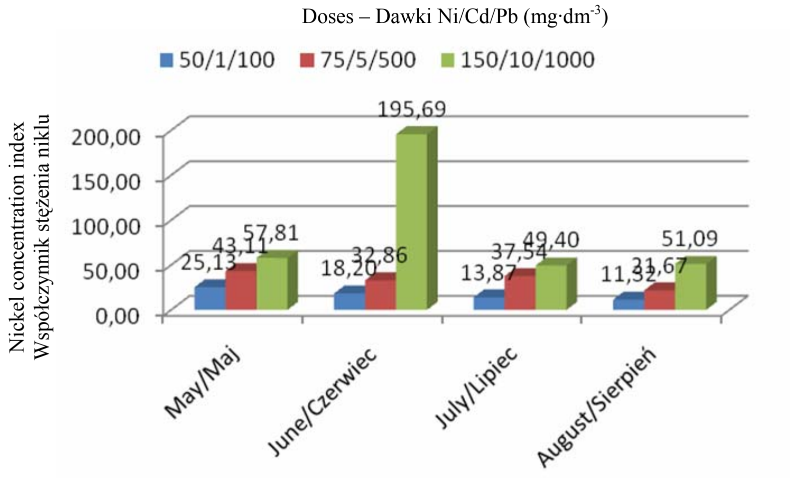

Fig. 8. Nickel concentration index in *Poa pratensis* L. 'Evora'
Ryc. 8. Współczynnik stężenia niklu dla *Poa pratensis* L. 'Evora'

In *Festuca arundinacea* Schleb. 'Asterix' in all the cuts the biggest nickel concentration index was found in plants growing in the substrate with a medium metal contamination (fig. 9). Similarly as in Kentucky bluegrass, in the substrate with medium heavy metal contamination the highest nickel concentration index was found in the month of June.

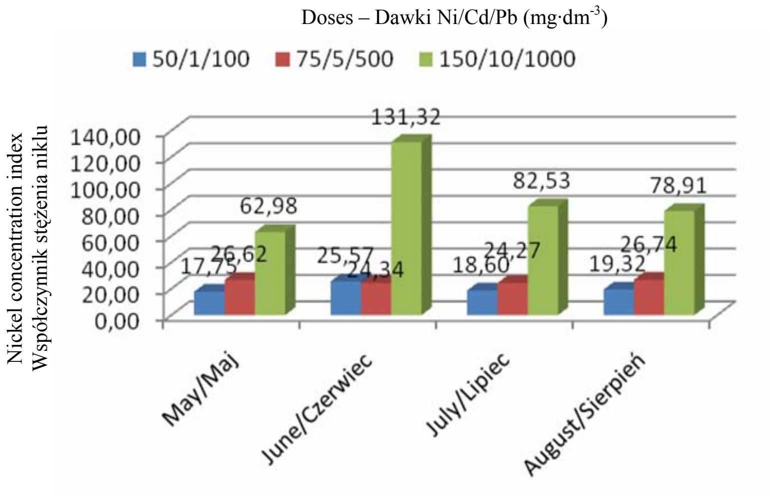

Fig. 9. Nickel concentration index in *Festuca arundinacea* Schleb. 'Asterix'
Ryc. 9. Współczynnki stężenia niklu dla *Festuca arundinacea* Schleb. 'Asterix'

In *Festuca rubra* L. *sensu lato* 'Jasper' in the June cut the highest nickel concentration index was observed in plants growing in the substrate, to which the highest dose of heavy metals was introduced, while it was the lowest for the substrate with their elevated content (fig. 10). A similar dependence in red fescue was observed in the July cut. The biggest nickel concentration index in August was recorded in red fescue growing in the substrate weakly contaminated with heavy metals.

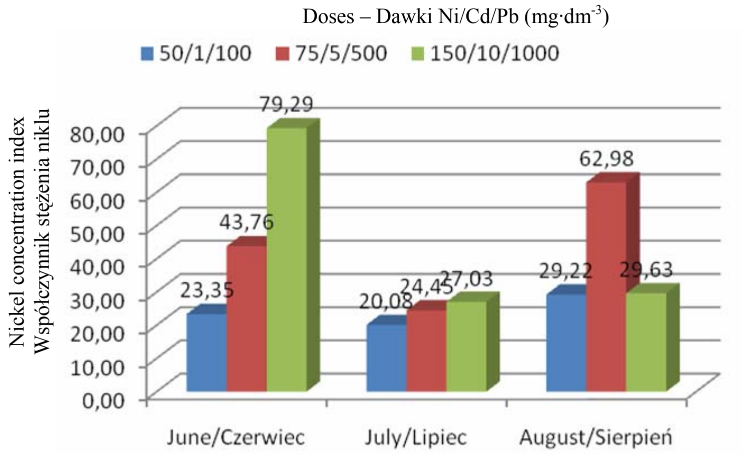

Fig. 10. Nickel concentration index in *Festuca rubra* L. *sensu lato* 'Jasper'
Ryc. 10. Współczynnik stężenia niklu *Festuca rubra* L. *sensu lato* 'Jasper'

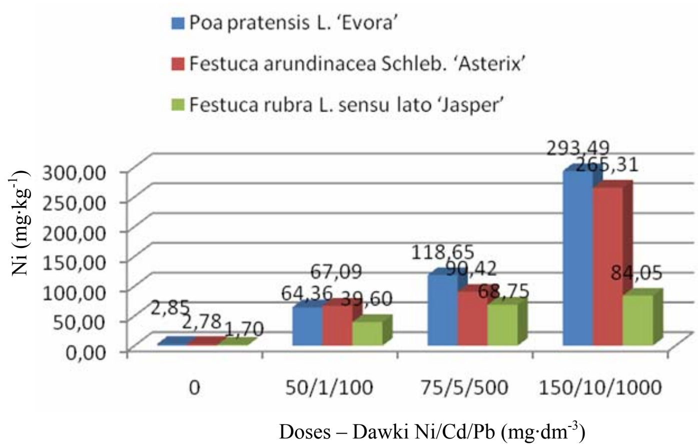

Fig. 11. Mean (from all harvests) nickel content in the aboveground parts of analysed species of lawn grasses (in d.m)
Ryc. 11. Średnia (ze wszystkich zbiorów) zawartość niklu w części nadziemnej badanych gatunków traw gazonowych (w s.m.)

Means nickel content (from all the harvests) in the aboveground parts of analysed grass species. Among the analysed grass species, growing in the substrate with weak and medium contamination with heavy metals, the highest mean (from all the harvests) nickel content was recorded in the aboveground parts of *Poa pratensis* L. 'Evora', while it was lowest in the aboveground parts of *Festuca rubra* L. *sensu lato* 'Jasper' (fig. 11). In the substrate with an elevated content of heavy metals the highest mean content was recorded in *Festuca arundinacea* Schleb. 'Asterix', while the lowest in the aboveground parts of *Festuca rubra* L. *sensu lato* 'Jasper'.

DISCUSSION

A considerable role in the contamination and degradation of the environment, including the soil medium, is played by heavy metals, which are characterised by the ability of their very high bioaccumulation [Baran 2000]. In the opinion of Buczkowski et al. [2002], the specific nature of soil contamination with heavy metals results from their chemical character, since they are elements which do not undergo processes of biodegradation or decomposition to simple compounds.

In the opinion of Baran [2000], the natural content of nickel in soils ranges from several to 50 $mg \cdot kg^{-1}$. This element is absorbed by hydrated iron and aluminium oxides, loam minerals and organic substances. Its solubility is increased by acidification of the soil medium.

In the conducted investigations, in order to obtain pH optimal for the tested species of lawn grasses within the range of 6.5–7.0, the substrates were limed with calcium carbonate at 6 g per 1 dm^3.

Relatively high amounts of Ni penetrate to the soil with fertilizers, primarily superphosphate and potash salt [Ruszkowska et al. 1996]. Atmospheric air pollution with nickel is closely related to its emission by the metallurgical industry and to the combustion of liquid fuels. Global emission is estimated at 100 thousand ton annually [Karaś 2000].

In the conducted analyses the substrate, apart from cadmium and lead, was artificially contaminated with nickel. Increasing doses represent different degrees of soil pollution with nickel: 50 mg $Ni \cdot dm^{-3}$ – an elevated content, 75 mg $Ni \cdot dm^{-3}$ – weak contamination, 150 mg $Ni \cdot dm^{-3}$ – medium contamination.

Nickel is an element of high mobility in the natural environment, with the soil–plant system playing a significant role in its cycle in ecosystems. Domańska [2009] claimed that crops differ in their potential to absorb this element, although it is usually easily absorbed, in a degree proportional to its concentration in the soil, until a toxic level is reached. Nickel in trace amounts is essential for plants and is considered to be a microelement [McElroy and Nason 1954]. It was found that it is essential for soy [Fujiwra and Kikuchi 1950] and prevents blister blight occurring in Chinese tea (*Camelia sinensis*) [Venkata 1961]. This metal may also be toxic to plants. However, there are considerable differences in phytoaccumulation and phytotoxicity of nickel, depending on the plant species [Spiak 1996, Gambuś 1997], as well as the form in which this metal is found [Spiak 1997] Soil properties are also important, e.g. pH, grain size composition, organic matter content as well as interactions between nickel and other trace elements, e.g. cadmium, zinc and copper [Kabata-Pendias and Pendias 1999, Badora 2002, Wall 2003].

Under normal conditions the content of nickel in plants most commonly ranges from 0.1 to 5 ppm Ni in dry matter [Lityński and Jurkowska 1982]. Kabata-Pendias and Pendias [1999] reported that the natural content of nickel in plants ranges from 0.05 to several $mg \cdot kg^{-1}$, optimally up to 3 $mg \cdot kg^{-1}$, depending on their species and organ. The level of up to 3200 $mg \cdot kg^{-1}$ was detected in plants from regions influenced by industrial pollution.

In the analysed species of lawn grasses, growing in the substrate to which heavy metals were not introduced (the control object), the content of nickel ranged from 1.05 $mg \cdot kg^{-1}$ (red fescue harvested in August) to 5.34 $mg \cdot kg^{-1}$ (reed fescue harvested in May). In turn, the highest nickel content in the aboveground parts (569.47 $mg \cdot kg^{-1}$) was found in *Poa pratensis* L. 'Evora' growing in the substrate with medium contamination with heavy metals, harvested in June. Baker and Chesnin [1974] reported that the concentration of 10 $mg \cdot kg^{-1}$ d.m. in plants indicates excessive accumulation of this metal in soil. Apart from the analysed lawn grasses growing in the substrate not contaminated with heavy metals, all of them were characterised by a content higher that 10 mg $Ni \cdot kg^{-1}$ d.m.

Among the analysed grass species, growing in substrates contaminated with heavy metals, *Poa pratensis* L. 'Evora' and *Festuca arundinacea* Schleb. 'Asterix' showed the highest capacity to accumulate nickel, while it was lowest in *Festuca rubra* L. *sensu lato* 'Jasper'. Red fescue in a study by Bosiacki and Wolf [2008 a, b] turned out to be a species exhibiting the highest capacity to accumulate cadmium and lead. It needs to be stressed that in this study the substrates, in which lawn grasses were growing, were separately contaminated with cadmium and separately with lead.

Some plants may exhibit tolerance to high concentrations of nickel and they accumulate it in high amounts [Lyon et al. 1970, Severne 1974].

Such a high accumulation of metals is facilitated by different mechanisms of tolerance, e.g. binding in cell walls, chelation and detoxication by cellular organic compounds (organic acids, phytochelatins), deposited in organelles metabolically inactive (the vacuole) or in external tissues of the trichome [Verkleij and Schat 1990]. Differences in the accumulation of heavy metals can depend also on the cultivar [Tyksiński and Kurdubska 2005].

Plants growing on soils contaminated with heavy metals should exhibit considerable tolerance to their high concentrations, which will not affect their growth and yielding. The increasing doses of nickel, cadmium and lead introduced to the substrate, applied in this study, irrespective of harvest dates, did not have a significant effect on fresh matter in the analysed species of lawn grasses. Despite the statistically non-significant differences in fresh matter of grasses a marked, evident reduction of matter content was observed in case of *Festuca rubra* L. *sensu lato* 'Jasper' growing in the substrate with medium contamination with heavy metals. In a study by Kukier and Chaney [2004] it was shown that the yield of shoots (in barley, wheat, fescue, beans, oat, maize and soy) was inversely proportional to the concentration of nickel in shoots. Those researchers also found that the phytotoxicity threshold needs to be assumed to be such a concentration of the metal, which could result in yield reduction. Soil application of nickel caused a reduction of yielding in maize, being proportional to the applied doses [Spiak 1997].

The analysed species of lawn grasses (*Poa pratensis* L. 'Evora', *Festuca arundinacea* Schleb. 'Asterix' and *Festuca rubra* L. *sensu lato* 'Jasper') may be used in the management of soils contaminated with nickel.

CONCLUSIONS

1. Increasing doses of heavy metals, irrespective of harvest date, did not have a significant effect on height and fresh matter of aboveground parts in *Festuca arundinacea* Schleb. 'Asterix' and *Festuca rubra* L. *sensu lato* 'Jasper'.
2. In *Poa pratensis* L. 'Evora' increasing doses of metals, irrespective of harvest date, when introduced to the substrate did not influence fresh matter of plants. However, they had an effect on plant height. The smallest plant height was found for the substrate, to which 150 Ni, 10 Cd and 1000 Pb mg·dm^{-3} were introduced.
3. After the completion of the experiment the lowest nickel content was recorded for the substrate, in which *Poa pratensis* L. 'Evora' was growing, except for the substrate weakly contaminated with heavy metals, in which no significant differences were observed in the content of nickel.
4. The highest content of nickel in the dry matter of the aboveground parts in *Poa pratensis* L. 'Evora' and *Festuca arundinacea* Schleb. 'Asterix', growing in all substrates, was recorded in the first (May) cut of grasses, except for *Poa pratensis* L. 'Evora' growing in the substrate with medium contamination with heavy metals, in which a higher Ni content was recorded in the June cut.
5. In the substrate with medium contamination with heavy metals the highest Ni content was recorded in the aboveground parts of *Festuca rubra* L. *sensu lato* 'Jasper' in June, while in plants growing in the other substrates no significant differences were found in the content of this metal.
6. Among the analysed grass species, growing in substrates contaminated with heavy metals, *Poa pratensis* L. 'Evora' and *Festuca arundinacea* Schleb. 'Asterix' turned out to be the species exhibiting the highest capacity to accumulate nickel. The lowest mean content of nickel was recorded in *Festuca rubra* L. *sensu lato* 'Jasper'.
7. The analysed species of lawn grasses, particularly *Poa pratensis* L. 'Evora' and *Festuca arundinacea* Schleb. 'Asterix', may be used in the management of soils contaminated with nickel.

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FITOEKSTRAKCJA NIKLU PRZEZ WYBRANE GATUNKI TRAW GAZONOWYCH Z PODŁOŻY ZANIECZYSZCZONYCH METALAMI CIĘŻKIMI

Streszczenie. W ostatnich lat wiele uwagi poświęca się skażeniu środowiska metalami ciężkimi. Za główne źródło tego zanieczyszczenia uważa się przemysłową działalność człowieka, spalanie paliw kopalnych, motoryzację, hutnictwo i inne procesy technologiczne. Na zanieczyszczenie środowiska metalami szczególnie narażone są tereny silnie uprzemysłowione i duże ośrodki miejskie. Poszukuje się metod taniego oczyszczania środowiska z metali ciężkich. Jedną z takich metod może być fitoremediacja, wykorzystująca rośliny do fitoekstrakcji tych metali. W przeprowadzonym doświadczeniu badano fitoekstrakcję niklu przez *Poa pratensis* L., odmiana 'Evora', *Festuca arundinacea* Schleb., odmiana 'Asterix' oraz *Festuca rubra* L. *sensu lato*, odmiana 'Jasper'. Wybrane gatunki traw gazonowych stosowane są w mieszankach trawnikowych. Rośliny posadzono w sztucznie zanieczyszczone metalami ciężkimi podłoże. Celem przeprowadzonych badań było stwierdzenie, który z zastosowanych gatunków traw gazonowych, posadzonych w podłożu zanieczyszczonym metalami ciężkimi będzie akumulował największe ilości niklu oraz czy wprowadzone wzrastające dawki metali ciężkich do podłoża będą miały wpływ na wzrost i świeżą masę części nadziemnych badanych gatunków traw gazonowych. Wzrastające dawki metali ciężkich, niezależnie od terminu zbioru nie wpłynęły istotnie na świeżą masę części nadziemnych badanych traw. Spośród badanych gatunków traw, rosnących w zanieczyszczonych metalami ciężkimi podłożach, gatunkiem wykazującym największą zdolność do akumulacji niklu okazała się *Poa pratensis* L. 'Evora' oraz *Festuca arundinacea* Schleb. 'Asterix'. Najmniejszą średnią zawartość niklu stwierdzono u *Festuca rubra* L. *sensu lato* 'Jasper'. Badane gatunki traw gazonowych, a zwłaszcza *Poa pratensis* L. 'Evora' i *Festuca arundinacea* Schleb. 'Asterix' mogą być wykorzystywane do zagospodarowania gleb skażonych niklem.

Słowa kluczowe: fitoremediacja, fitoekstrakcja, nikiel, trawy gazonowe

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